Phosphorus Forms and Concentrations in Soils under Different Land Use in Southwestern Saskatchewan

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ABSTRACT

Phosphorus (P) is an essential nutrient for all organisms. Insufficient or poorly available P can limit crop growth, requiring P fertilization. However, excess P can move from land to water, impairing water quality. Balancing P fertilization to maximize crop growth while limiting P loss requires a detailed knowledge of P forms and cycling. Different land use practices are expected to alter P cycling through differences in microbial populations, P inputs from vegetation and fertilizer, and management practices that affect soil chemical and physical properties. Understanding P cycling under different land uses can help to improve P use efficiency in agriculture. Presented here are the preliminary results of a research project investigating P forms and cycling in soils under different land uses in southwestern Saskatchewan.

INTRODUCTION

Phosphorus is essential for all organisms. Research into soil P has primarily focused on deficiencies and excess. Low soil P concentrations can limit plant growth, requiring the need for fertilization. However, commercial chemical P fertilizers are primarily derived from rock phosphate, a resource with finite stocks (e.g. Cordell et al., 2009). As such, strategies are needed to improve the P efficiency of agriculture (e.g. Richardson et al., 2011), especially in soils with low P concentrations. In contrast, intensive agriculture and over-fertilization, particularly with manure, have produced high soil P concentrations in some regions, beyond what is needed for plant growth and exceeding the soil P storage capacity (e.g. Jarvie et al., 2013). This excess P may be lost from soils to water bodies in runoff and erosion, where it can cause excess growth of nuisance algae (Elser and Bennett, 2011; Jarvie et al., 2013).

Managing soil P under conditions from deficiency to excess requires detailed information about both P concentrations and P speciation, because the chemical forms of P will determine their bioavailability and environmental reactivity (Condron et al., 2005; Pierzynski et al., 2005).

Phosphorus in soil can be divided into organic P (bonded to carbon (C) in some way), and inorganic P (Condron et al., 2005; Pierzynski et al., 2005). Inorganic P is divided into orthophosphate, pyrophosphate and polyphosphate. At the pH of most soils, orthophosphate is found as H_2PO_4- or HPO_4^{2-}. Polyphosphates are chains of orthophosphate, ranging in length from two orthophosphate groups (pyrophosphate) to >100. Organic P is divided into orthophosphate monoesters, orthophosphate diesters and phosphonates, based on the bond of P to C.

Orthophosphate monoesters have the general structure $ROPO_3^{2-}$ (where R is an organic moiety), with one orthophosphate per C group, and include sugar phosphates (e.g. glucose 6-phosphate), mononucleotides and inositol phosphates. Orthophosphate diesters ($R_1O(RO)PO_2^-$, where R and R_1 are C moieties), have two C groups per orthophosphate. These include nucleic acids, phospholipids and lipoteichoic acid. Phosphonates differ from other organic P forms because they have a direct C-P bond (not an ester bond through O). These have the structure [$RP(O)(OH)_2$], and include 2-aminoethyl phosphonic acid (AEP), antibiotics such as fosfomycin, and agricultural chemicals such as the herbicide glyphosate.

Methods to characterize P include measures of total soil P, total soil organic P, soil test P to measure plant-available P and assess the need for P fertilization, and methods to characterize specific P forms, such as ^{31}P-NMR spectroscopy (O'Halloran and Cade-Menun, 2008). Assays are also available to determine the activity of enzymes that convert organic P forms to orthophosphate. These enzymes are produced by plants and microbes.

Different land use practices are expected to alter P cycling through differences in microbial populations, P inputs from vegetation and fertilizer, and management practices that affect soil chemical and physical properties. Understanding P cycling under different land uses can help to improve P use efficiency in agriculture. In light of this, the objective of this study was to characterize P forms and cycling in soils under four common land-use practices in SW Saskatchewan: annual cropland, native prairie, tame pasture (crested wheatgrass) and roadsides.

SAMPLING SITES AND METHODS

Samples were collected from 5 locations in southwestern Saskatchewan. Each location contained adjacent sites for each land use type. Soils at all sites were well-drained Orthic Brown Chernozems. Cores (0-30 cm depth; 5 per land use type per location) were collected in July 2013. In the lab, they were coarsely sieved and well mixed. Fresh samples were used for enzyme assays (Tabatabai, 1994) and microbial analysis, and were extracted with NaOH-EDTA for ^{31}P-NMR (Cade-Menun and Preston, 1996; Cade-Menun, 2005). A subsample from each site was oven-dried (30^{o}C), and this was used to determine total P by digestion (Parkinson and Allen, 1975; O'Halloran and Cade-Menun, 2008)), total organic P by the ignition method (Saunders and Williams 1955; O'Halloran and Cade-Menun, 2008), and soil test P by the bicarbonate (Olson P) method (Sims, 2009). Reactive P in these solutions was measured with the molybdate blue method (Murphy and Riley, 1962). ^{31}P-NMR analysis was conducted at Stanford University.

PRELIMINARY RESULTS AND DISCUSSION

There were no significant differences in soil total P or total organic P (Fig. 2 and 3). Bicarbonate P was significantly higher in roadside soils than the other land uses (Fig. 4), and enzyme activities were also higher in road-side soils, particularly alkaline monoesterase (Fig. 5). Both the preliminary ^{31}P-NMR results (Fig. 6) and the total organic P results (Fig. 3) show that more than 60% of the total P in soils of all land use types was organic P, of which the orthophosphate monoesters (phytate, inositol phosphates, sugar phosphates, mononucleotides) comprised the highest percentage of total P. Enzyme activity was significantly correlated with total organic P, bicarbonate P, the orthophosphate monoesters and diesters (Table 1), suggesting that plant-available P is controlled by mineralization of organic P by plant and microbial enzymes in these soils, although less so in the cereal soils than in other land use types.

Continuing work for this project includes the identification of specific P forms with ^{31}P-NMR; microbial community analysis, including arbuscular mycorrhizal fungi (AMF) spore abundance composition of the AMF community; and analysis of other soil factors, including nutrients and physical properties.

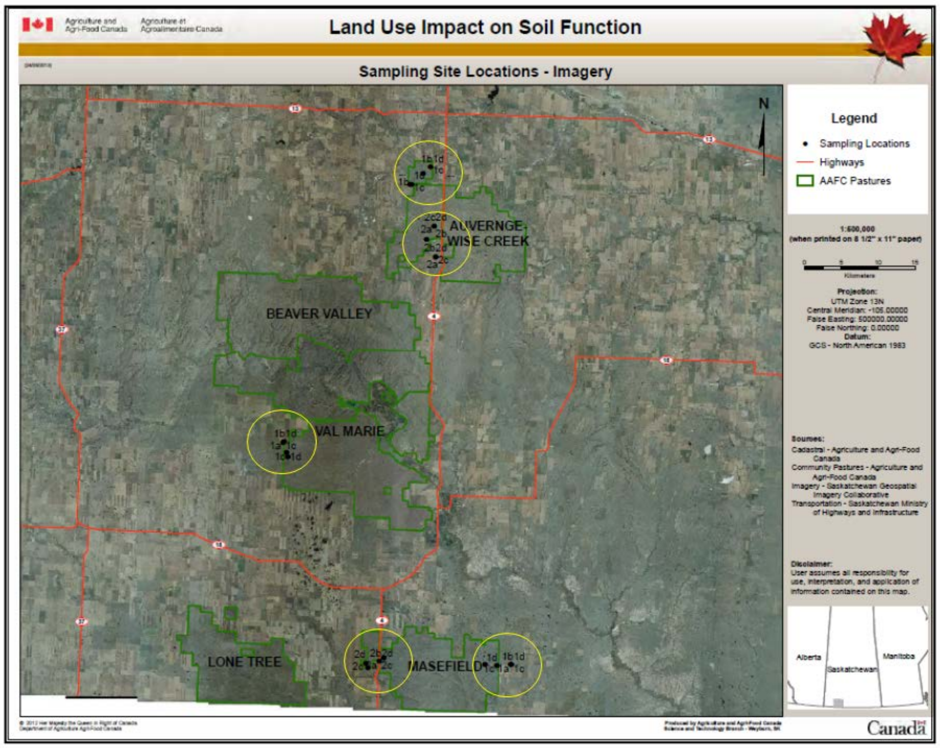
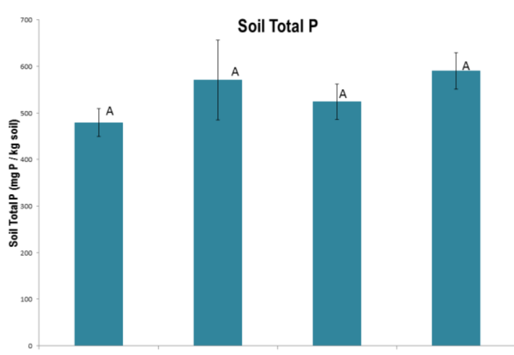


Fig. 1: Sampling site locations in southwestern Saskatchewan.



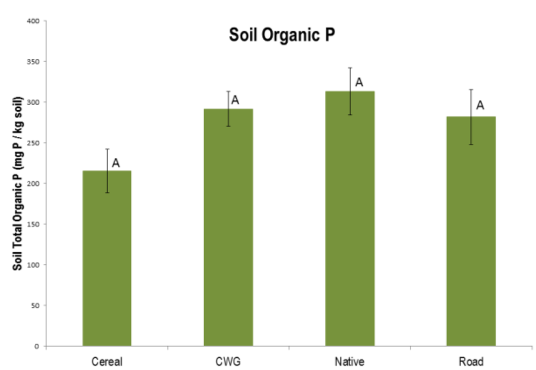
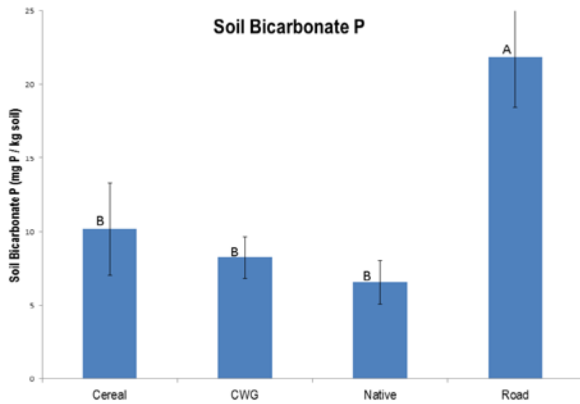


Fig. 2 (left): Soil total P; Fig. 3 (right): Soil total organic P. Values are means (n = 5); error bars are standard errors of the mean. CWG is crested wheatgrass, native is native prairie, cereal is annual cropland, and road is roadside.



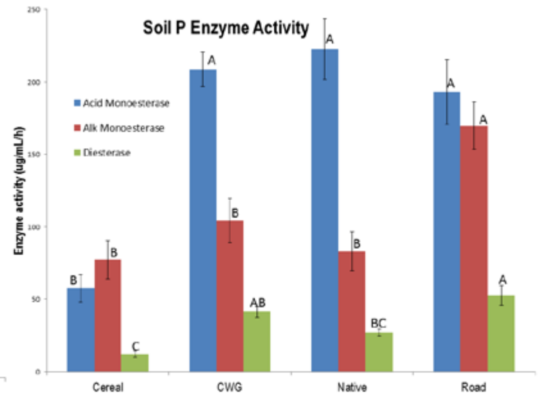


Fig. 4 (left): Soil bicarbonate P; Fig. 5 (right): Soil phosphorus enzyme activity. Values are means (n = 5); error bars are standard errors of the mean. CWG is crested wheatgrass, native is native prairie, cereal is annual cropland, and road is roadside.

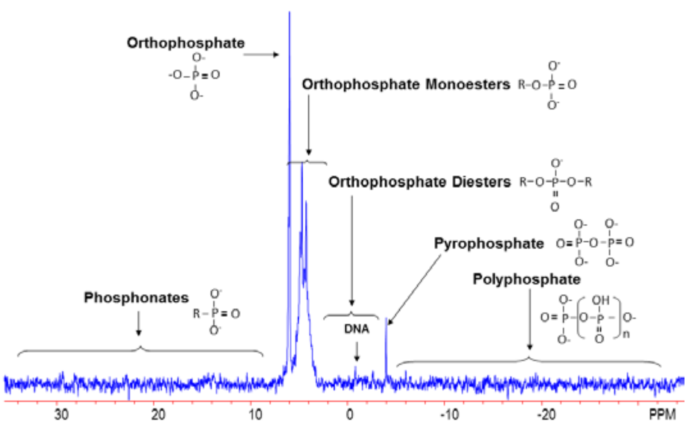


Fig. 6: ^{31}P-NMR spectrum of soil P forms.

Table 1: Correlation analysis of P pools, P forms and enzyme activities.

	Bicarb P	Alk Pase	Acid Pase	Diesterase	OrthoP	Monoesters	Diesters
Total P		0.61**		0.59**			
Org. P	0.57**		0.79**				
Bicarb. P				0.45*	0.61**		
Alk. Pase						0.43*	0.60**
Acid Pase						0.44*	
Diesterase						0.45*	

Bicarb: bicarbonate-extractable (Olson's) P; Alk Pase: alkaline phosphatase activity; Acid Pase: acid phosphatase activity; Diesterase: diesterase activity; OrthoP: orthophosphate, determined by ^{31}P-NMR; Monoesters: orthophosphate monoesters, determined by ^{31}P-NMR; Diester: orthophosphate diesters, determined by ^{31}P-NMR.
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

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